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Rasipuram - 637 408, Namakkal Dist., Tamil Nadu.

Subject Code and Name: 23GES15 & Manufacturing Process

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Unit-I CASTING PROCESSES

9 hours

Sand casting process- Steps; Core; Sand Testing; Molding Processes, Gating system, Solidification Phenomena, Melting Furnaces, Special casting methods - Centrifugal casting; Hot chamber and cold chamber die casting; Investment casting; Shell mold casting; Plaster mold casting; CO2 mold casting. Casting Defects and remedies.

Sand casting

Casting is a manufacturing process in which a **liquid material (typically metal) is poured into a mold to solidify and take the shape of the mold cavity**. It is commonly used for producing **complex shapes** that would be difficult to achieve through other methods such as forging or machining. Casting can be done using a variety of materials, including metals, plastics, and ceramics.

Sand Casting

Sand casting is one of the most widely used casting methods, particularly for metals. It involves creating a mold from a mixture of sand, water, and a binder material. The mold is used to shape molten metal into the desired part.

Sand Casting Process: Steps

Sand casting is a widely used method for creating metal parts by pouring molten metal into a sand mold. Here are the **steps involved** in the sand-casting process:

Pattern Creation

- **Description:** A pattern is made in the shape of the part to be cast. The pattern is typically made from a material that can withstand high temperatures, such as metal, wax, or plastic.
- **Materials:** Metal, plastic, wood, or wax.
- **Process:** The pattern is a slightly larger replica of the final part to allow for shrinkage during cooling.

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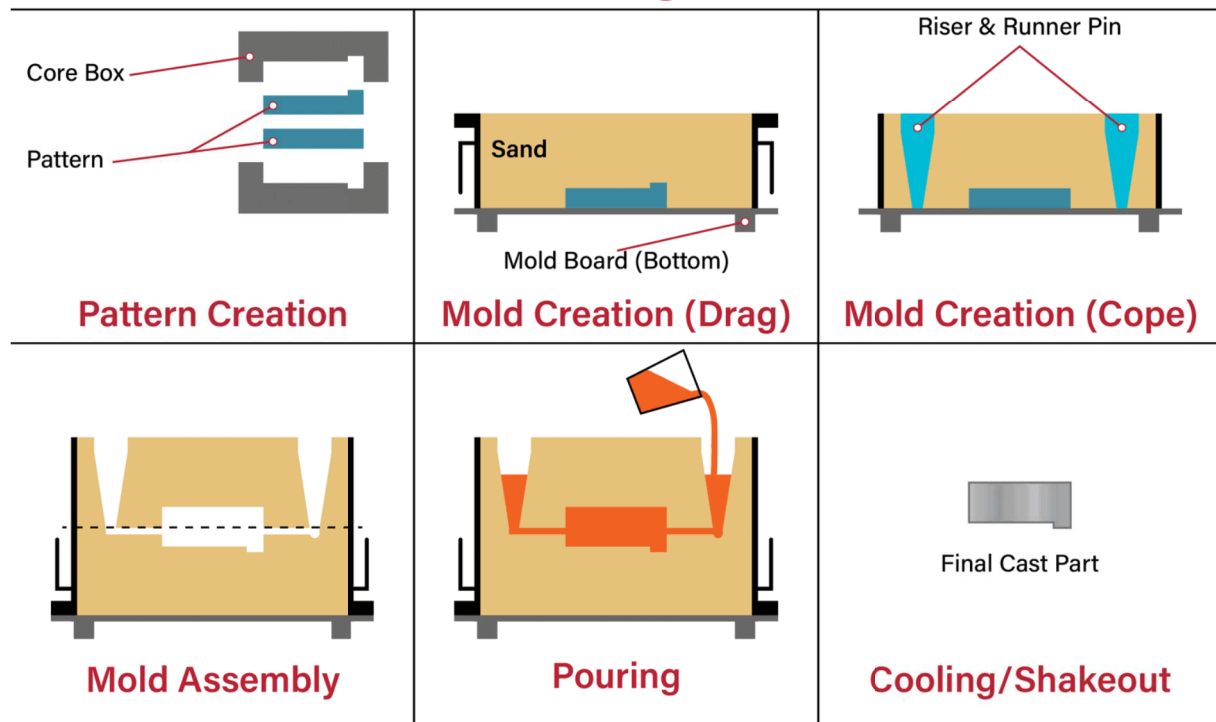
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Mold Preparation

- **Description:** The pattern is embedded in a mold material, typically a mixture of sand, clay, and water. This sand mixture is compacted to create a mold around the pattern.
- **Types of Sand:** The most common is **green sand**, which is a mixture of sand, clay, and water. Alternatively, dry sand or resin-bonded sand can be used depending on the type of casting required.
- **Mold Box (Flask):** The pattern is placed inside a mold box, also known as a flask, which holds the sand mixture in place.
- **Process:** The sand is packed around the pattern, compacted, and then allowed to harden to form the mold.

Sand Casting Process



Pattern Removal

- **Description:** After the mold is prepared and hardened, the pattern is carefully removed. The pattern must be removed without damaging the mold.
- **Process:** This can be done by simply pulling the pattern out of the sand or by shaking or vibrating the mold. If using a more complex pattern (e.g., hollow or internal cavities), the pattern may be melted out (lost wax method) or broken away.

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Mold Cavity Formation

- **Description:** After removing the pattern, a cavity is left in the mold in the shape of the part to be cast.
- **Process:** The mold cavity is cleaned to remove any remaining pattern residues. In some cases, **core** material (sand cores) may be inserted into the mold to form internal passages or hollow spaces within the casting.

Gating and Pouring System Design

- **Description:** A gating system is created in the mold to guide the molten metal into the cavity. The gating system includes runners, sprues, and risers.
- **Sprue:** A vertical channel that directs molten metal into the mold.
- **Runner:** Horizontal channels that distribute the molten metal to various parts of the mold.
- **Risers:** Small reservoirs that allow for the escape of gases and provide extra molten metal to compensate for shrinkage during solidification.

Pouring Molten Metal

- **Description:** The molten metal is poured into the mold through the gating system.
- **Materials:** Metals like aluminum, steel, cast iron, copper, or bronze are typically used in sand casting.
- **Process:** The metal should be poured at a temperature sufficient to fill the mold completely without causing defects such as cold shuts or misruns. The molten metal should flow smoothly into the mold cavity, filling all sections of the mold.

Cooling and Solidification

- **Description:** After the metal is poured, it must cool and solidify to take the shape of the mold cavity.
- **Process:** Cooling time depends on the size and complexity of the part, as well as the type of metal used. Cooling is typically done in the mold to control the rate at which the metal solidifies.

Mold Removal

- **Description:** Once the metal has cooled and solidified, the sand mold is removed to reveal the casting.
- **Process:** The sand mold is typically broken away or mechanically removed. Depending on the type of sand used, the mold can be crushed or shaken off the casting.

Cleaning and Finishing

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- **Description:** The casting usually requires cleaning and finishing processes to remove any excess material (like sprues, runners, and risers) and smooth the surface.
- **Processes:**
 - **Cutting:** The sprue, runners, and risers are cut off.
 - **Grinding and Polishing:** To smooth out rough surfaces and edges.
 - **Shot Blasting:** To remove sand residues.
 - **Machining:** For precise dimensions and additional finishing.
 - **Heat Treatment:** If required, to relieve stresses or improve material properties.

Inspection and Quality Control

- **Description:** After cleaning and finishing, the casting is inspected for defects, dimensional accuracy, and surface quality.
- **Methods:** Visual inspection, ultrasonic testing, radiographic testing, and dimensional measurements are commonly used for quality control.

Core: Definition

A **core** in casting is a pre-formed mass of material, usually made of sand, that is placed inside a mold to create internal cavities, holes, or other complex features in the cast part. Cores are used to produce voids or intricate shapes that cannot be made using the external mold alone.

A **core print** is a feature or projection on the pattern or mold used in sand casting to support and position a **core** within the mold cavity. The core print provides a secure location for the core and ensures that it is held in place during the pouring of molten metal. Without a core print, the core could shift or move, which would lead to defects in the final casting.

Core Making Steps in Sand Casting

The process of creating cores for sand casting is a crucial step to form internal features such as cavities, holes, or intricate shapes within the casting. Below are the typical steps involved in **core making**:

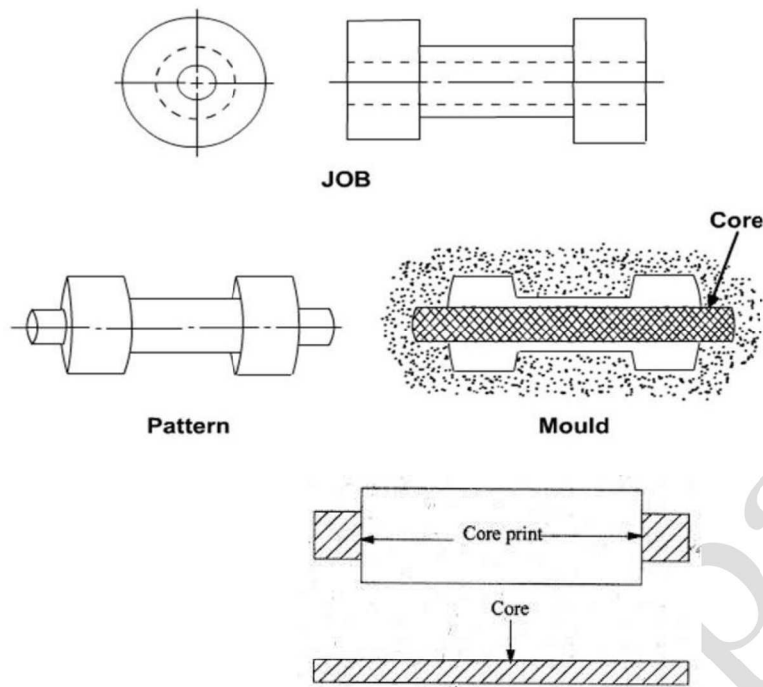


Figure 1.37 Core and core print

1. Core Design and Material Selection

- **Description:** The first step is to design the core based on the internal features that need to be created in the casting. The material of the core is also selected, typically sand mixed with a binder to give the core its desired shape and strength.
- **Common Core Materials:**
 - **Green Sand** (sand with clay and water binder)
 - **Resin-bonded Sand** (sand mixed with chemical resin)
 - **Oil-bonded Sand** (oil binder mixed with sand)
 - **Shell** (used for thin-walled and precision applications)

2. Core Box Preparation

- **Description:** A **core box** is a mold used to shape the core. The core box is typically made of metal or wood and is designed to form the exact shape of the core.
- **Process:** The core box is cleaned and lubricated to ensure the core material can be removed easily after it solidifies.



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3. Sand Mixing

- **Description:** Sand is mixed with a binder (e.g., clay, resin, or oil) to form the core material. The binder helps the sand hold its shape during the core making and casting process.
- **Mixing Process:**
 - The sand and binder are mixed thoroughly to ensure a uniform consistency.
 - **Additional additives** like hardeners or accelerators might be added to improve the strength of the core material.

4. Core Formation (Packing the Core Box)

- **Description:** Once the core box is ready and the sand mixture is prepared, the sand is packed into the core box.
- **Process:**
 - The core box is filled with the sand mixture, and it is compacted around the core box cavity to form the internal shape.
 - The packing should be uniform to ensure that the core will have the desired strength and accuracy.
 - Vibrating or ramming the sand mixture is often used to ensure the sand is packed tightly.

5. Core Baking or Curing (Optional)

- **Description:** After the core is formed, it may need to be **baked** or **cured** to further harden the binder and give the core its strength.
- **Process:**
 - The core is placed in an oven or furnace to bake, which helps the binder cure and harden.
 - The temperature and time of baking depend on the binder used and the core's size.

6. Core Drying (for Green Sand Cores)

- **Description:** If the core is made using green sand, it needs to be dried to remove excess moisture before it is used in the mold.
- **Process:**
 - The core is allowed to dry at room temperature or in a drying oven.
 - Drying ensures the core is solid and free of moisture, preventing defects during the casting process.



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7. Core Removal from Core Box

- **Description:** After the core has solidified or cured, it is removed from the core box.
- **Process:**
 - The core is carefully extracted from the mold.
 - In some cases, the core box may be split to remove the core.
 - The core must be handled carefully to prevent damage.

8. Core Inspection and Repair

- **Description:** Once the core is removed, it is inspected for defects such as cracks, shrinkage, or weak spots. If necessary, repairs are made.
- **Process:**
 - Cracks are patched with fresh core sand or resin.
 - Any rough edges or imperfections are smoothed out.

9. Core Insertion in Mold

- **Description:** Once the core is complete and inspected, it is placed inside the outer mold cavity to create the desired internal features.
- **Process:**
 - The core is carefully positioned inside the mold cavity before the molten metal is poured in.
 - Cores can be held in place by the surrounding mold material or additional support structures (called **core prints**) may be used to ensure proper positioning.

Core Making Steps in Sand Casting:

1. **Design & Material Selection:** The core design is created based on internal features needed in the casting. Sand mixed with binders like clay or resin is chosen as the core material.
2. **Core Box Preparation:** A core box (mold) is made, often from metal or wood, to shape the core.
3. **Sand Mixing:** Sand is mixed with a binder to ensure it holds its shape and strength during the casting process.
4. **Core Formation:** The sand mixture is packed tightly into the core box, using methods like ramming or vibrating to ensure uniformity.
5. **Core Curing (Optional):** The core is baked or cured in an oven to harden the binder.
6. **Core Removal:** After curing, the core is carefully removed from the core box.

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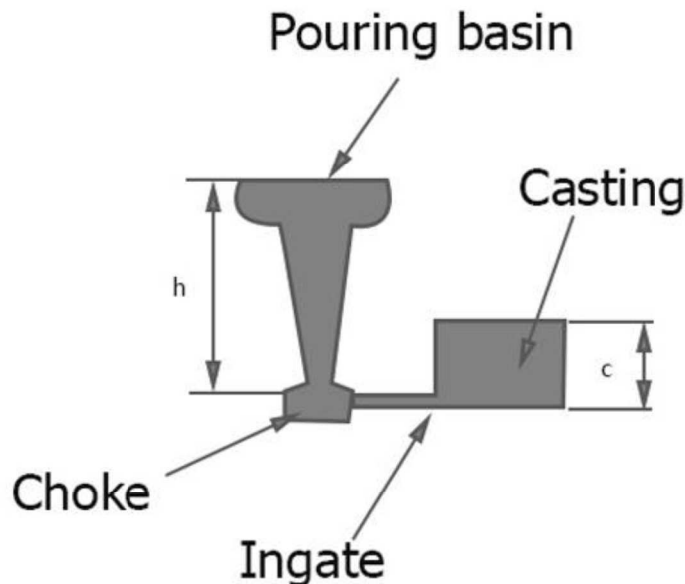
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7. **Core Inspection:** The core is inspected for defects, cracks, or weakness, and repaired if necessary before being placed in the mold.

Gating System



Gating System

A **gating system** in casting refers to the network of channels that directs molten metal from the pouring basin into the mold cavity. It consists of various components that control the flow of metal, allowing it to fill the mold efficiently while minimizing defects like air pockets, turbulence, and cold shuts.

Main Components of the Gating System:

1. **Sprue:** The vertical channel that carries molten metal from the pouring basin into the runner.
2. **Runner:** Horizontal channels that distribute the molten metal from the sprue to the different sections of the mold.
3. **Gate:** The opening through which molten metal flows into the mold cavity.
4. **Riser:** A reservoir that allows the molten metal to flow into the mold to compensate for shrinkage as it cools.

Steps in Designing a Gating System:

1. **Determine Pouring Rate:** Based on the material and part size, the optimal pouring rate is determined to avoid defects like turbulence and oxidation.

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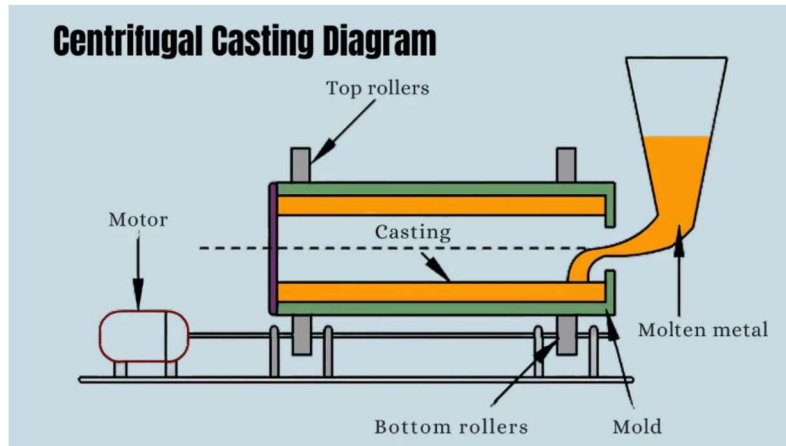
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2. **Sprue and Runner Sizing:** The dimensions of the sprue and runner are calculated to ensure proper flow and minimize metal wastage.
3. **Gate Location and Size:** The gate must be strategically placed to ensure even filling of the mold cavity and avoid trapping air.
4. **Riser Placement:** Risers are placed at locations where shrinkage is expected, ensuring that the metal has enough volume to solidify without voids.

Difference Between Moulding and Casting

Aspect	Moulding	Casting
Definition	Moulding is the process of shaping a material (usually plastic, metal, or rubber) into a desired form by using a mold.	Casting involves pouring molten metal or material into a mold to form a solid shape once it cools and hardens.
Material Used	Materials like plastics, rubber, clay, or metals can be molded.	Primarily molten metals, but also molten plastics or glass.
Process Type	It can be a continuous or semi-continuous process, typically forming objects in one piece.	Involves pouring liquid material (metal or plastic) into a mold to form a solid part.
Method	It involves shaping a material by forcing it into a mold, sometimes under pressure.	The material is poured into a mold to solidify into the desired shape.
Used For	Making items like plastic containers, rubber parts, and molds for casting.	Manufacturing metal parts, jewelry, sculptures, and some plastic objects.
Time	Generally faster than casting, as solidification and cooling occur quickly.	The process takes longer, as cooling and solidifying the molten material take time.
Examples	Injection molding, blow molding, compression molding.	Sand casting, die casting, investment casting.

Centrifugal Casting



Centrifugal casting has been developed as a manufacturing process for producing cylindrical and hollow components by utilizing the principles of centrifugal force. The molten metal has been poured into a rotating mold, allowing the metal to be distributed evenly along the mold walls due to centrifugal action. This technique has been applied to create high-quality, defect-free castings with improved mechanical properties.

Working Principle of Centrifugal Casting

- The mold has been rotated at high speeds along its axis.
- Molten metal has been introduced into the mold while it is in motion.
- Due to centrifugal force, the metal has been pressed outward against the mold walls, forming a uniform structure.
- The lighter impurities and gases have been pushed toward the inner surface, which can be machined away after solidification.
- The casting has been left to cool and solidify before removal from the mold.

Advantages of Centrifugal Casting

- **High Purity and Strength:** Impurities and gases have been separated toward the inner surface.
- **Grain Refinement:** Fine-grained structure has been achieved due to rapid solidification.
- **Material Savings:** No need for risers, reducing material wastage.
- **Improved Mechanical Properties:** The density and strength of the castings have been enhanced.
- **Cost-Effective for Hollow Parts:** Large cylindrical components have been produced with minimal defects.

Limitations of Centrifugal Casting

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- **High Equipment Cost:** Special rotating molds and machinery have been required.
- **Limited to Certain Shapes:** Only hollow and symmetrical components have been manufactured effectively.
- **Machining Required:** The inner surface has been rough and often requires machining.
- **Complex Process Parameters:** Speed, temperature, and pouring rate must be precisely controlled.

Applications of Centrifugal Casting

- **Pipes and Tubes:** Used in water supply, oil pipelines, and gas distribution.
- **Cylinder Liners and Engine Sleeves:** Automotive and aerospace applications.
- **Gear Blanks and Flywheels:** High-strength machine components.
- **Jet Engine Components:** High-performance turbine rings and sleeves.
- **Biomedical Implants:** Used in dental and orthopedic implants.

Centrifugal casting has been recognized as a highly efficient and precise metal casting technique for producing hollow cylindrical parts with superior mechanical properties. With advancements in automation and material science, its application range has been expanded, making it a crucial process in various industries.

Types of Centrifugal Casting

Centrifugal casting has been classified into three major types:

1. True Centrifugal Casting

- The mold has been rotated around its central axis, and molten metal has been poured directly into it without any core.
- Used for producing pipes, tubes, and hollow cylindrical components.
- No external pressure has been required as the centrifugal force itself helps in shaping the material.

2. Semi-Centrifugal Casting

- The mold has been rotated, but a central core has been used to create a hollow cavity.
- Suitable for producing parts like wheels, pulleys, and gear blanks.
- The force has been used to improve material density while allowing for a solid center.

3. Centrifuging (Centrifugal Die Casting)

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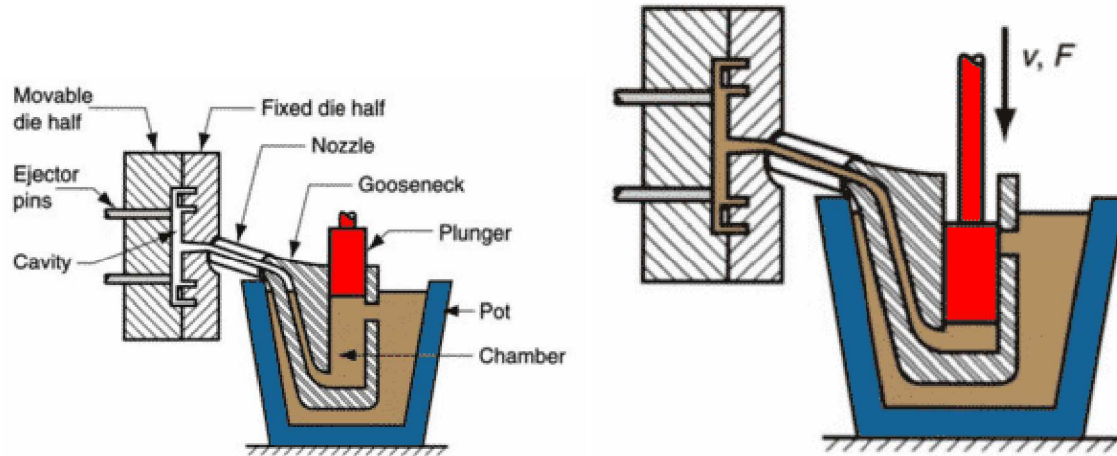
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- A series of molds have been arranged radially around a central sprue, and molten metal has been forced into these molds.
- Used for small, detailed castings such as jewelry, precision components, and medical implants.
- Ensures uniform metal distribution in intricate shapes.

Materials for Centrifugal Casting

Typical materials that can be centrifugal cast are metals, cements, concretes, glass, and pottery materials. Typical metals cast are iron, steel, stainless steels, and alloys of nickel, aluminum, and copper, magnesium.

Hot Chamber Die Casting



Hot chamber die casting is a type of die casting that uses alloys with low melting temperatures (i.e., Zinc and Magnesium alloys). Using alloys with high melting temperatures would result in damage to the gooseneck, nozzle, and other components.

In a hot chamber die casting machine, the fixed die half is called a cover die, which is mounted to a stationary platen (large plate to which each die half is mounted) and aligns with the nozzle of the gooseneck. The movable die half is the ejector die and is mounted to a movable platen, which slides along tie bars. The metal is contained in an open holding pot, placed in the furnace, and melted to the desired temperature. The molten metal flows into the shot chamber when the plunger is in the “up” position. As the plunger moves down, it forces the molten metal through a gooseneck and into the die at injection pressures ranging from 1,000 – 5,000 psi. The machine pushes the moving platen towards the cover die and holds it closed with tremendous pressure until the molten metal is injected. The plunger remains in the “down” position to hold the pressure while the casting “cools off.” After solidification, the plunger is retracted, and the cast part is either ejected, manually removed from the machine or pushed off the cover die. This ejection system, which includes an ejector die and ejector pins, allows the casting to be pushed out while releasing the die halves.

Hot chamber die casting has been developed as a high-speed manufacturing process used for producing complex metal components with high precision. This process has been commonly applied for casting low-melting-point metals such as zinc, magnesium, and lead alloys. The molten metal has been maintained in a heated reservoir, allowing for rapid injection into the die cavity.

Working Principle of Hot Chamber Die Casting



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1. **Molten Metal Reservoir:** The metal has been melted and stored in an integrated heating chamber attached to the die-casting machine.
2. **Injection Mechanism:** A plunger or piston has been immersed in the molten metal, drawing a controlled amount into the injection system.
3. **Die Filling:** The plunger has been actuated to force molten metal into the die cavity under high pressure.
4. **Solidification:** The molten metal has been rapidly cooled and solidified within the die.
5. **Ejection:** The solidified casting has been removed from the die after cooling.
6. **Recycling:** Excess metal from the sprue, runners, and overflows has been reused for future casting.

Characteristics of Hot Chamber Die Casting

- The machine has been equipped with an integral melting furnace.
- High-speed operation has been achieved due to continuous metal supply.
- Suitable for small to medium-sized parts requiring high precision.
- Shorter cycle times have been possible compared to cold chamber die casting.

Advantages of Hot Chamber Die Casting

- **Fast Production Rates:** High-speed injection and short cooling times have enabled mass production.
- **Minimal Metal Wastage:** The integrated system allows for efficient metal utilization.
- **Superior Surface Finish:** Smooth and detailed components have been produced without extensive post-processing.
- **Longer Die Life:** Lower operating temperatures have reduced thermal stress on the die.
- **Consistent Quality:** The automated process ensures uniformity and dimensional accuracy.

Limitations of Hot Chamber Die Casting

- **Restricted to Low-Melting-Point Metals:** Aluminum and other high-melting alloys cannot be cast using this process.
- **Limited Component Size:** Suitable only for small to medium-sized parts.
- **Corrosion of Components:** Continuous exposure to molten metal can degrade machine parts.
- **High Initial Cost:** The setup and equipment have been expensive, requiring significant investment.

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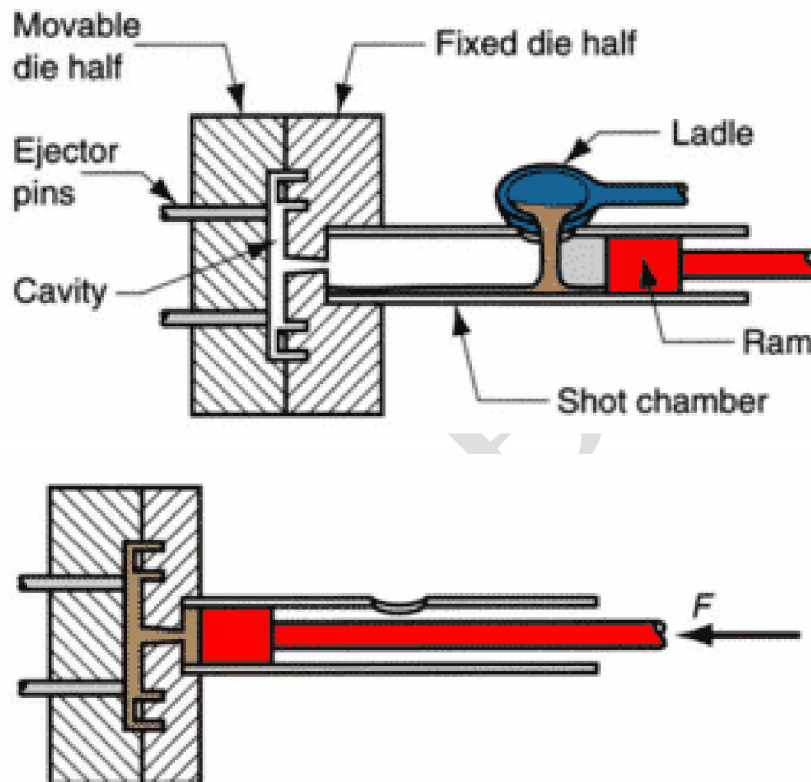
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Applications of Hot Chamber Die Casting

- **Automotive Components:** Small engine parts, carburetor housings, and brackets.
- **Consumer Electronics:** Casings for mobile phones, laptop components, and connectors.
- **Household Appliances:** Handles, knobs, and decorative fittings.
- **Toy Manufacturing:** Zinc-based toy parts with intricate details.
- **Medical Equipment:** Precision components in diagnostic devices.

Cold Chamber Die Casting



Cold chamber die casting is a type of die casting that is used for alloys with high melting temperatures (e.g., Aluminum and some Magnesium alloys). In contrast to hot chamber die casting (pumping molten metal into the machine), molten metal is ladled from the furnace into the shot chamber through a pouring hole. While the general function of the cold chamber machine is similar to that of the hot chamber, the cold chamber works with a horizontal orientation and does not have a gooseneck. Instead, the plunger forces metal through the shot chamber into the die at pressures ranging from 2,000 to 20,000 psi. The plunger holds the pressure and retracts after solidification. The clamping unit and mounting of dies are set up the same as for a hot chamber; Prepared by **Dr. S. Boopathi**, Professor/ Mechanical Engineering / Muthayammal Engineering College, Namakkal, Tamil Nadu, India.



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however, the cover die for a cold chamber machine does not have a gooseneck or nozzle and, therefore, aligns directly from the shot chamber.

Cold chamber die casting has been developed as a high-pressure casting process used for producing high-strength and complex metal components. Unlike hot chamber die casting, the molten metal has been kept in a separate furnace and ladled into the injection system manually or automatically. This process has been suitable for casting metals with high melting points, such as aluminum, brass, and copper alloys.

Working Principle of Cold Chamber Die Casting

1. **Molten Metal Preparation:** The metal has been melted in an external furnace and kept at a controlled temperature.
2. **Metal Transfer:** A measured amount of molten metal has been ladled into the cold chamber injection system.
3. **High-Pressure Injection:** A hydraulic or mechanical plunger has forced the molten metal into the die cavity under high pressure.
4. **Solidification:** The metal has been cooled and solidified within the die.
5. **Ejection:** The solidified casting has been pushed out of the die using ejector pins.
6. **Trimming and Recycling:** Excess material (sprue, runners, and flash) has been removed and often recycled.

Characteristics of Cold Chamber Die Casting

- The injection system has been kept separate from the molten metal to prevent excessive heat exposure.
- The process has been slower than hot chamber die casting due to manual metal transfer.
- Suitable for high-melting-point metals that cannot be cast in a hot chamber system.
- High pressures (ranging from 2,000 to 20,000 psi) have been applied for precise shaping.

Advantages of Cold Chamber Die Casting

- **Suitable for High-Melting-Point Metals:** Aluminum, brass, and copper alloys have been efficiently cast.
- **Improved Die Durability:** The separate furnace setup has reduced wear on machine components.
- **Stronger Castings:** Higher mechanical strength and better thermal resistance have been achieved.



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- **Good Surface Finish:** Smooth and detailed components have been produced, minimizing post-processing.
- **Minimal Porosity:** The high-pressure injection has resulted in denser and defect-free castings.

Limitations of Cold Chamber Die Casting

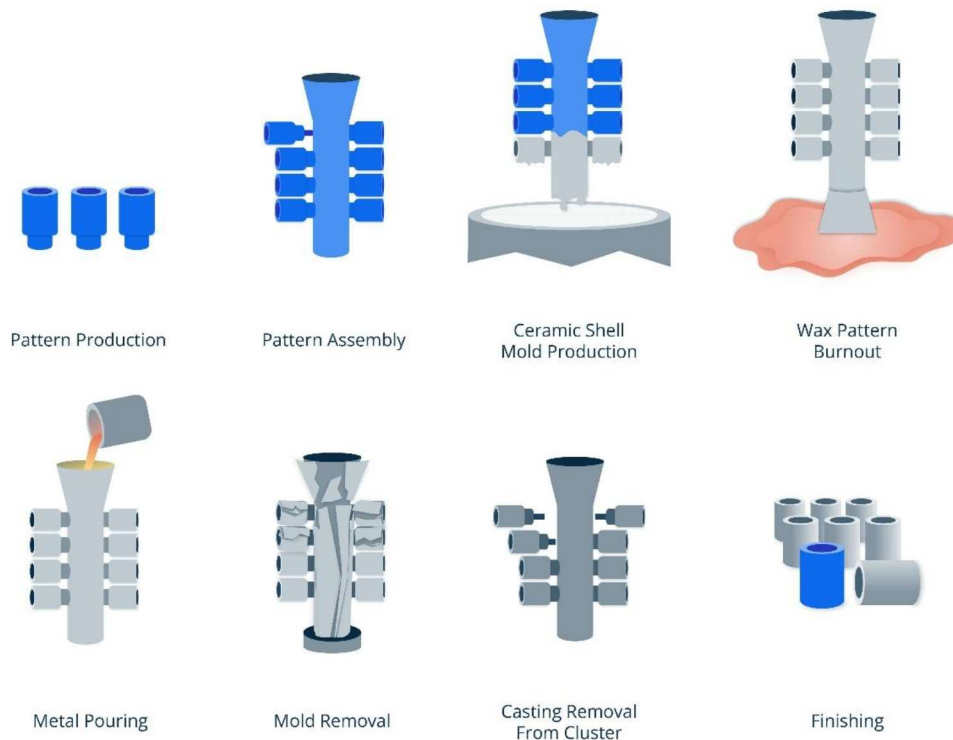
- **Slower Cycle Time:** Manual metal ladling has increased production time.
- **High Equipment Cost:** Requires a separate furnace and complex injection system.
- **More Material Wastage:** The sprue and runners contribute to metal loss.
- **Thermal Shock on Dies:** Repeated contact with molten metal has led to wear and tear on dies.

Applications of Cold Chamber Die Casting

- **Automotive Industry:** Engine blocks, transmission cases, and alloy wheels.
- **Aerospace Components:** Structural and heat-resistant parts.
- **Electronics Industry:** Housings for electrical connectors and enclosures.
- **Industrial Equipment:** Pump housings, valve bodies, and brackets.
- **Defense and Military Applications:** Lightweight, high-strength parts for weapons and vehicles

Investment casting

Investment Casting Process



Investment casting is a precision casting process used to create complex and intricate metal parts with high dimensional accuracy and fine surface finishes. This casting method is ideally suited to producing relatively high-quality components with intricate details, delicate features, and tight tolerances. Investment casting is commonly used in industries such as: aerospace, automotive, jewelry, and medical devices, in which high precision and intricate designs are essential. It also produces castings with very tight tolerances and high dimensional accuracy. Investment castings typically have smooth and fine surface finishes. Investment casting can be used with a variety of materials, including various metals and alloys. It can also produce parts with complex shapes, internal cavities, and thin walls that are challenging for other casting methods.

How Investment Casting Differs From Other Types of Casting

All casting methods use a heat-resistant cavity that is the shape of the desired part as a volume to be filled with liquid metal, which is removed once solidified. The means by which the cavity is formed is the primary differentiator of casting methodologies. Die casting uses a two-part (or more) hardened-steel cavity tool that is expensively and precisely machined from billet material. Sand casting forms a cavity by packing sand with a binding agent around a reusable pattern or



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master of the part. Investment casting forms the cavity by drying and then kiln baking a skin of refractory material over a pattern or master that is sacrificial.

Precision and extent of detail differ greatly between casting methods. Die casting is high precision, although gravity (poured) die casting is less precise than the various forms of pressure die casting. Pressure die casting facilitates compensation for shrinkage, which retains/reflects the shape and dimensions of the cavity more faithfully in the cast part. Pressure die-cast parts can maintain very high levels of detail, so long as that detail can be extracted from the tool features. Sand casting is of moderate precision because the process does not lend itself to forming very accurate and repeatable cavities. It can maintain only relatively thick sections and coarse details. Investment casting is renowned for its combination of precision and fine detail while avoiding the major up-front costs of die casting.

Industries That Use Investment Casting

Investment casting is most used in industries in which precision, complexity, and fine details are crucial, and volumes are insufficient to justify the cost of die casting. The aerospace industry uses investment casting for the manufacture of high-complexity gas turbine components for gas flow such as turbine blades and fuel components. In automotive applications, it is used to manufacture components for low-volume and race vehicles, heavy goods/construction equipment, tractors, and agricultural machinery. In the medical sector, it is used to produce parts for MRI machines, wheelchairs, hospital beds, operating room equipment, and surgical tools.

The Basics of Investment Casting

Investment casting works by pre-applying coatings to the pattern—before investment casting mold creation, or to the mold—once it is fired. This serves several important purposes. Refractory coatings are applied to the interior surface of the mold to provide a barrier between the mold material and the molten metal. This reduces oxidation, contamination, and marking. An internal stucco layer in the mold can improve the release and texture of the surface to improve cosmetics by concealing slight flaws. Parting compounds applied to the mold surfaces ease the release of the casting at breakout.

Thermal barrier coatings applied selectively to the pattern can control the cooling rate and prevent rapid solidification. Anti-penetration coatings applied to the pattern can reduce the penetration of melt into the refractory material, to improve the quality of the surface finish.

Step-by-Step Process of Investment Casting

Listed and discussed below is the step-by-step process of investment casting:

1. Create and Assemble the Wax Patterns

There are three basic routes to delivering the precision wax patterns that are the starting point for investment casting. For decorative items and one-off products such as jewelry or technical items

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for which precision is a lower priority, it is common to hand carve the wax master to the desired dimensions/shape. This starts with either assembling preformed wax shapes to form the part or extracting the part from a solid block by cutting or melting locally. For mass-produced items that will be investment cast in relatively large volumes, it is generally preferred to build a steel tool that forms a wax casting cavity. A more recent development has been the ability to 3D print (rapid prototype) relatively small wax parts, to allow volume production without the cost of a wax casting tool. This is particularly useful in iterative development, allowing multiple generations of small changes to be trailed without huge cost.

2. Mount the Wax Patterns

Attach a feeder structure consisting of a sprue and channel to the part to allow the fill to be successful. Attach the part and feeder structure to a casting board that forms the structure to allow the flask (the completed cast tool) to stand securely. Any areas that are liable to vent poorly require air passage features to be added. Where multiple parts are to be cast in one pour, these structures are best established as individual cavities/galleries. Feed them from a single sprue/pour point. Care and experience are required to enable effective fill when the gallery structure or part geometry is more complex.

3. Make a Mold Shell

A first immersion in the correctly formulated slurry will coat the surfaces of the pattern/sprue/support structure. Once the assembly is coated, it can be withdrawn and allowed to drip. Once drained, apply a layer of stucco—dry powder sprinkled all over to stabilize the first layer. Repeat the dip/drain/stucco steps until sufficient thickness is developed all over. The rest/drying time between layers can be several hours, to allow sufficient drying and stabilization for each layer. Set aside to completely dry, giving this enough time for the coating to become firm and rigid.

4. Remove the Wax

Bake the completed and dried flask to remove the wax and fully integrate the refractory coating. The supplier-recommended temperatures and durations for this stage are dependent on the type of material such as: water glass, clay, and silica. At the end of this baking process, the mold or flask will be fully fused into a single, strong body. The wax will have been fully volatilized or burned off. The cavity or cavities, sprue, and galleries will be clear and open. The support structure of investment and braces will be able to support the structure, ready to fill.

5. Melt and Cast the Metal

Lift the crucible with tongs and pour the contents into the upper opening to the sprue. Fill/charging should continue until the entire structure is full. This is usually confirmed by the visible presence of molten metal in the upper vents, showing good flow through.

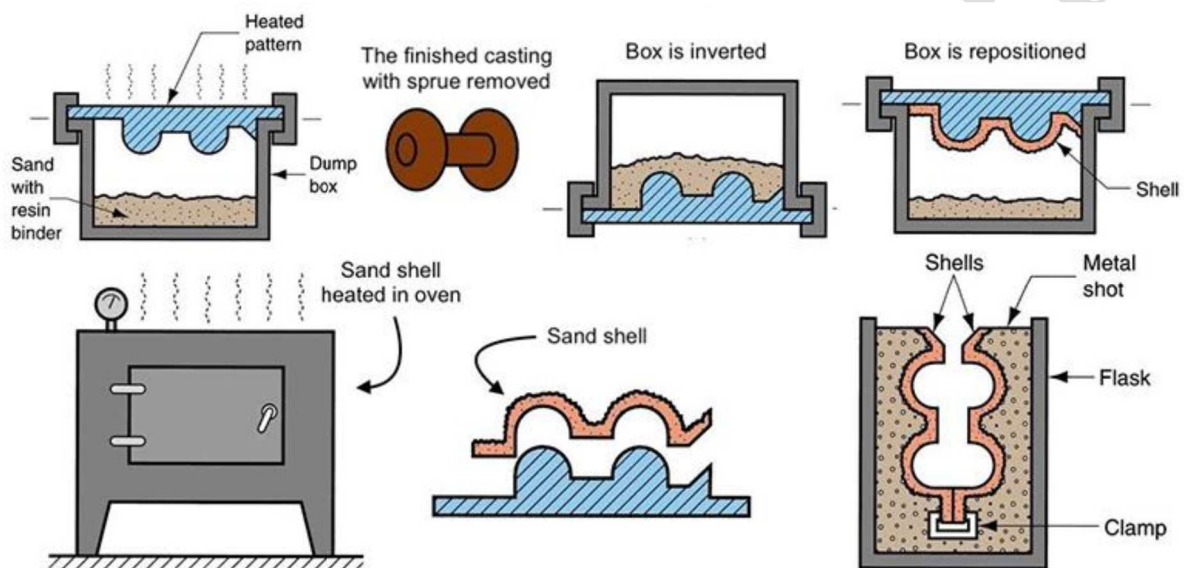
6. Finalize the Castings

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When the cast has cooled, break away the refractory material without distorting the newly cast metal. In some cases, such as for simple and robust castings in stainless steel and bronze, this can be a vigorous and rapid process. Where more delicate features and softer metals such as gold and silver are present, much greater care must be taken.

The removal of cast material from sprue, vents, and supports will damage the desired casting. Any cosmetic damage can be repaired using die grinding, sawing, and clipping followed by surface restoration by sanding and polishing as required.

Shell mold casting



Shell molding is a metal casting technique which involves pouring molten metal into a disposable mold. The mold in shell mold casting is a thin-walled shell made by enclosing a pattern in a sand-resin combination. Many shell molds are created using the design of a metal piece in the form of the desired portion. Higher manufacturing rates are possible with reusable patterns, and complex geometries can be cast using disposable molds. A metal pattern, oven, sand-resin mixture, dump box, and molten metal are all necessary for shell mold casting. Shell moulding is a flexible and precise casting method that can be utilized to create castings of top-notch quality. The steps involved in the shell moulding process are quite simple.

Step 1: Pattern creation

A metallic pattern having a shape of a desired casting is made in one-half carbon steel material. The goal is to create a shell moulding pattern that closely resembles the part or component that will be cast. Two pieces of a different metal, usually iron or steel, are joined together to form the pattern, which is usually shaped to match the intended shape of the finished part or component. In



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In addition to steel and iron, other materials are frequently used, such as aluminium for low-volume manufacturing or graphite to cast the reactive elements.

Step 2: Creating a mold

During the creation of the mold, each pattern half is heated somewhere from 175–375°C and coated with a lubricant to facilitate removal. The heated pattern is fastened to the dump box, which is filled with a resin binder and sand combination. The dump box is inverted thereby allowing the sand-resin mixture to coat the pattern. The mixture around the pattern forms a shell after being partially cured by the heated pattern. Each pattern half and the surrounding shell are cured to completion in the oven and then the shell is ejected from the pattern.

Step 3: Shell mold assembly

The entire shell mould is created by joining two shells and tightly clamping them together. The two shell pieces must be completely linked by utilizing glue or other fasteners and properly secured before the shell mould casting process is complete. Then comes the assembly part when the core and shell mold is ready. The core is taken out of its core box and the shell mould is taken out of its pattern. Glue, or glue used in conjunction with other fasteners, is used to tightly seal the two pieces together. If inserting a core is necessary, it should be done before sealing the mould. Following that, a flask will be filled with the shell mould, which will be supported by a piece of backing material.

Step 4: Pouring the molten metal

Pouring molten metal into the cavity of the shell mould is the fourth step in the shell-casting process. Several types of metals and alloys, including steel and iron, are used in the shell-casting process. No matter the attribute, the metals or alloys are heated to a liquid condition and then poured into the cavity of the shell mould to create a firm shell.

Step 5: Cooling

The molten metals are then allowed to cool and solidify into the final shell-casting process shape. The pattern parts should typically be stored at room temperature. When pattern portions cool, the molten metal progressively hardens into a protective shell in the shape of the final casting.

Step 6: Trimming and Cleaning

The mould can be broken and the casting removed once the molten metal has cooled. Trimming and cleaning processes are required to remove any excess material in the shell molding process and get rid of any extra metal in the feed system and any sand in the mold.

Working Principle of Shell Casting

1. **Pattern Preparation:** A heated metal pattern (typically made of iron or steel) has been coated with a fine mixture of sand and thermosetting resin.



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2. **Shell Formation:** The coated pattern has been inverted to allow excess sand to fall off, leaving a thin layer of the sand-resin mixture on the surface.
3. **Curing:** The mold has been further heated to harden the resin, forming a strong shell.
4. **Mold Removal:** The shell has been stripped from the pattern and baked for additional strength.
5. **Assembly:** Two shell halves have been joined to form the complete mold.
6. **Metal Pouring:** Molten metal has been poured into the shell mold cavity.
7. **Cooling & Solidification:** The metal has been allowed to cool and solidify.
8. **Casting Extraction:** The shell mold has been broken away to retrieve the final casting.

Characteristics of Shell Casting

- A thin-walled mold has been formed using resin-coated sand.
- The process has provided **better accuracy and surface finish** than traditional sand casting.
- Suitable for both **ferrous and non-ferrous** metals, including steel, iron, and aluminum alloys.
- The mold-making process has been **partially automated**, increasing production efficiency.

Advantages of Shell Casting

- **High Dimensional Accuracy:** Tolerances as low as ± 0.2 mm have been achieved.
- **Smooth Surface Finish:** Finer grain sand has produced better-quality surfaces compared to conventional sand casting.
- **Reduced Machining Needs:** Near-net-shape castings have minimized post-processing.
- **Improved Strength and Durability:** The hardened shell mold has withstood high temperatures and pressures.
- **Mass Production Feasibility:** The automation of mold creation has enabled high-volume manufacturing.

Limitations of Shell Casting

- **Higher Cost:** Resin-coated sand and heated patterns have increased the overall production cost.
- **Limited Mold Reusability:** Shell molds have been single-use and cannot be reused like traditional sand molds.



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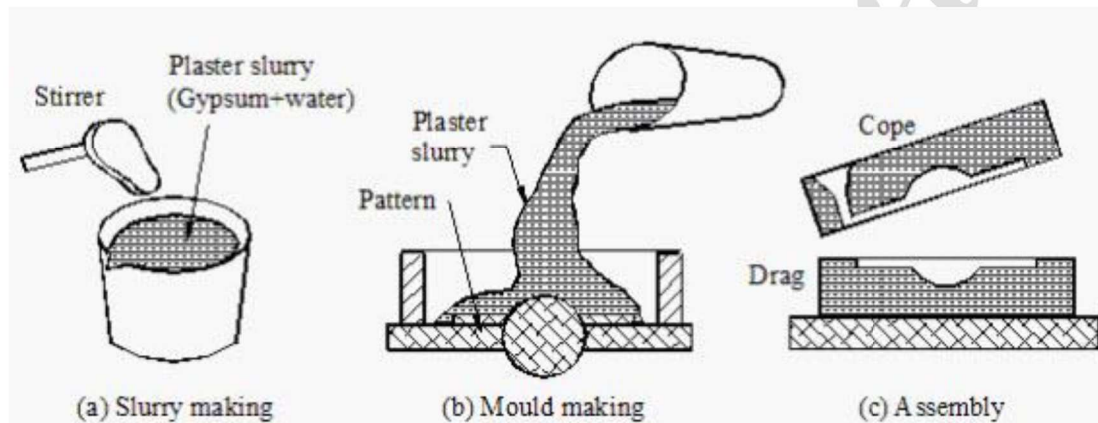
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- **Size Restrictions:** More suitable for small to medium-sized castings due to mold fragility.
- **Environmental Concerns:** The burning of resin has released fumes and pollutants.

Applications of Shell Casting

- **Automotive Industry:** Cylinder heads, camshaft housings, and engine components.
- **Aerospace Components:** Lightweight and high-precision parts.
- **Industrial Machinery:** Pump housings, valve bodies, and turbine blades.
- **Defense and Firearms:** Weapon parts, trigger mechanisms, and gear housings.
- **Medical Equipment:** Precision surgical and orthopedic instruments.

Plaster mold casting



Plaster mould casting process is also known as ceramic mould casting process. This process is used for casting objects of aluminium, lead, tin, magnesium, bronze alloys. In this process, moulds are prepared by pouring plaster (or gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) around the pattern. Patterns for plaster mould casting process can be made from wood, metal, plastic etc (preferably brass match plate pattern). Wood patterns not generally used due to extended contact with water. Plaster mould casting process is illustrated in Figure 1.

The process consists of preparing plaster slurry by mixing gypsum with silica flour, silica sand and water (see Figure 1(a)). When mixed with water, the gypsum re-crystallizes as it dehydrates, which causes the plaster to set by the interlocking of crystals. The slurry thus prepared is poured over the metal pattern kept in cope, as shown in Figure 1(b). Plaster slurry readily flows around pattern, capturing its fine details and good surface finish. The mould is slightly vibrated to ensure slurry filling all cavities. The initial setting requires few minutes (15 minutes) after the pouring of slurry and then the pattern is removed from the hardened slurry. The drag portion is also made in the same way. Cope and drag are dried in ovens at $120\text{--}260^\circ\text{C}$ to remove moisture. While the mould halves are still hot from the drying oven, they are quickly assembled / clamped, Figure 1(c). Assembled mould is poured with molten metal immediately to minimize the absorption of

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moisture from the atmosphere. Castings, after solidification and cooling, are removed from the moulds with high-pressure water jet. Using this process dimensional accuracy of the order of 0.008-0.01 mm can be obtained. Typical products made using plaster moulds include aircraft parts, gears, valves, ornaments etc.

Working Principle of Plaster Mold Casting

1. **Pattern Creation:** A pattern (usually made of plastic, wax, or metal) has been prepared in the shape of the final component.
2. **Mold Formation:** A slurry of **plaster, water, and additives** has been poured over the pattern and allowed to set.
3. **Mold Drying:** The mold has been heated at **120-260°C (250-500°F)** to remove moisture and strengthen the mold.
4. **Pattern Removal:** The pattern has been carefully removed from the hardened plaster mold.
5. **Mold Assembly:** The mold has been divided into two halves, which are reassembled before metal pouring.
6. **Metal Pouring:** Molten metal has been poured into the cavity of the mold.
7. **Cooling & Solidification:** The metal has been allowed to solidify within the mold cavity.
8. **Casting Extraction:** The plaster mold has been broken away to reveal the final casting.
9. **Finishing Operations:** Trimming, machining, and surface finishing have been applied if necessary.

Characteristics of Plaster Mold Casting

- The mold has been made from plaster of Paris mixed with water and other strengthening additives.
- Suitable for producing **thin-walled, detailed, and high-precision parts**.
- Provides **excellent surface finish** with minimal machining requirements.
- Mostly used for **non-ferrous metals**, such as **aluminum, magnesium, zinc, and copper alloys**.
- Not suitable for **high-temperature metals**, such as steel and cast iron, as the plaster mold cannot withstand extreme heat.

Advantages of Plaster Mold Casting

- **High Dimensional Accuracy:** Achieves tolerances of ± 0.1 mm, reducing machining needs.
- **Superior Surface Finish:** Smooth and detailed surfaces with minimal defects.
- **Good Reproducibility:** Complex shapes and fine details have been accurately replicated.



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- **Reduced Shrinkage Defects:** Plaster molds provide better heat insulation, minimizing thermal contraction.
- **Low Tooling Cost:** The mold-making process has been inexpensive compared to permanent molds.

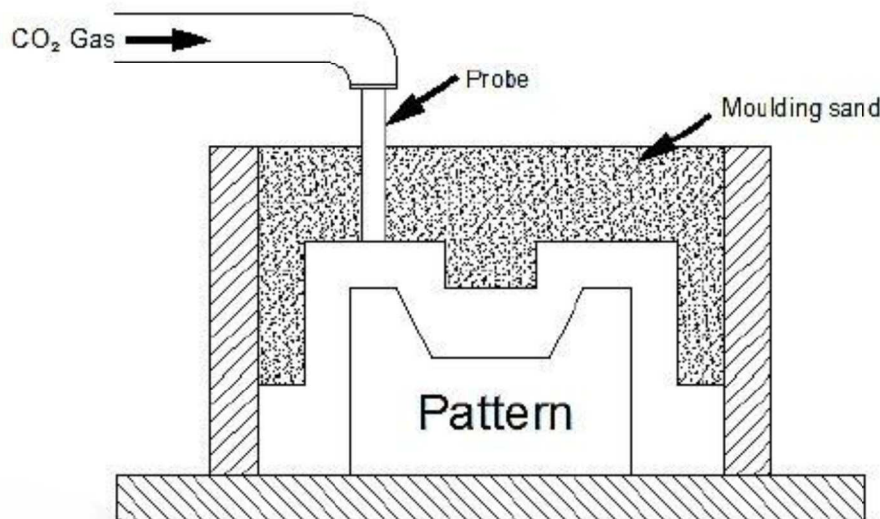
Limitations of Plaster Mold Casting

- **Limited to Non-Ferrous Metals:** Cannot be used for high-melting-point metals like steel or cast iron.
- **Longer Production Time:** Mold drying and preparation take longer compared to sand casting.
- **Fragile Molds:** Plaster molds are brittle and can break easily during handling.
- **Environmental Concerns:** Disposal of used plaster molds creates waste management issues.

Applications of Plaster Mold Casting

- **Aerospace Industry:** Thin-walled and intricate aluminum components.
- **Automotive Industry:** Prototype parts and small precision components.
- **Medical Equipment:** Surgical tools and orthopedic implants.
- **Artistic and Decorative Items:** Sculptures, ornaments, and jewelry castings.
- **Industrial Machinery:** Small gears, valves, and electronic housings.

CO₂ mold casting



CO₂ mold casting has been developed as an advanced sand casting process that uses **carbon dioxide gas (CO₂) to harden the mold**. Unlike traditional sand casting, where binders such as clay or resins have been used, **sodium silicate (Na₂SiO₃) binder** has been mixed with sand and

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hardened by exposing it to CO₂ gas. This process has been widely used for **rapid mold production with improved strength and dimensional accuracy**.

Working Principle of CO₂ Mold Casting

1. **Pattern Preparation:** A pattern has been created using wood, metal, or plastic.
2. **Sand Mixing:** Silica sand has been mixed with **sodium silicate (water glass) binder** to form a moldable mixture.
3. **Mold Formation:** The sand mixture has been packed around the pattern to create the mold cavity.
4. **CO₂ Gas Hardening:** The mold has been exposed to **carbon dioxide gas**, which reacts with sodium silicate to form **silicic acid gel (SiO₂·H₂O)**, rapidly hardening the mold.
5. **Pattern Removal:** The hardened mold has been separated from the pattern.
6. **Metal Pouring:** Molten metal has been poured into the mold cavity.
7. **Cooling & Solidification:** The metal has been allowed to cool and take the shape of the mold.
8. **Casting Removal:** The hardened mold has been broken away to retrieve the final casting.
9. **Finishing Operations:** The casting has been trimmed, cleaned, and machined if necessary.

Chemical Reaction in CO₂ Hardening

The reaction between **CO₂ gas and sodium silicate** binder has produced a **silica gel**, which binds the sand particles together:



This reaction has resulted in a **quick setting mold**, eliminating the need for traditional drying or baking processes.

Characteristics of CO₂ Mold Casting

- **Rapid mold hardening** using CO₂ gas exposure.
- **Stronger and more rigid molds** compared to conventional sand casting.
- Suitable for **ferrous and non-ferrous** metals, including cast iron, steel, aluminum, and bronze.
- No need for heat treatment or baking, reducing energy consumption.

Advantages of CO₂ Mold Casting

- **Faster Production:** Molds harden instantly upon CO₂ exposure, reducing processing time.
- **High Dimensional Accuracy:** Produces precise and detailed castings with minimal shrinkage.



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- **Stronger Molds:** Can withstand higher pouring temperatures and pressures.
- **Lower Energy Consumption:** No drying ovens or heat curing required.
- **Reusability of Sand:** Unused sand can be recycled with minimal processing.

Limitations of CO₂ Mold Casting

- **High Binder Cost:** Sodium silicate has been more expensive than conventional clay binders.
- **Brittle Molds:** CO₂-hardened molds can be fragile and prone to cracking.
- **Difficult Sand Reclamation:** Used sand requires chemical treatment to be reusable.
- **Short Working Time:** Once mixed, the sand must be molded quickly before it starts hardening.

Applications of CO₂ Mold Casting

- **Automotive Industry:** Engine blocks, cylinder heads, and brackets.
- **Aerospace Components:** High-strength and lightweight parts.
- **Pipe and Valve Manufacturing:** Heavy-duty industrial castings.
- **Machine Tool Industry:** Precision components for machinery.
- **Artistic and Decorative Castings:** Intricate sculptures, statues, and jewelry.

Casting Defects and Remedies

Defect Name	Description	Causes	Remedies
Porosity	Small holes or voids inside the casting.	- Gas entrapment in molten metal. - Moisture in mold or core. - High pouring temperature.	- Use degassing agents. - Reduce moisture in sand. - Proper venting in mold.
Blowholes	Smooth, round cavities in the casting surface or inside.	- Excessive gas formation. - Poor mold permeability. - High moisture content in sand.	- Improve mold venting. - Reduce moisture in sand. - Control pouring speed.



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Defect Name	Description	Causes	Remedies
Shrinkage Defect	Internal cavities due to metal contraction during solidification.	- Insufficient feeding system. - Improper riser design. - High pouring temperature.	- Use proper riser design. - Modify gating system. - Use chills to control cooling.
Misrun	Incomplete filling of mold cavity.	- Low pouring temperature. - Slow pouring rate. - High viscosity of molten metal.	- Increase pouring temperature. - Modify gating system. - Improve fluidity of metal.
Cold Shut	Incomplete fusion between two metal streams.	- Low pouring temperature. - Poor fluidity of molten metal. - Incorrect gating design.	- Increase metal temperature. - Improve mold design. - Ensure proper gating system.
Hot Tears (Cracks)	Irregular cracks in the casting due to uneven cooling.	- High thermal stress. - Poor mold design. - Sudden cooling.	- Use proper mold material. - Provide uniform cooling. - Modify casting design.
Mold Shifting	Misalignment of mold halves, causing an offset in the casting.	- Improper alignment of cope and drag. - Loose mold box.	- Ensure proper mold clamping. - Use alignment pins in molds.
Sand Inclusion	Sand particles embedded in the casting.	- Loose sand in mold cavity. - Weak mold strength.	- Improve sand quality. - Increase mold strength.



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Defect Name	Description	Causes	Remedies
		- High pouring velocity.	- Reduce pouring speed.
Rat Tail and Buckle	Surface irregularities or wavy depressions on casting.	- High expansion of molding sand. - Poor sand conditioning. - Excess moisture.	- Use low-expansion sand. - Improve mold hardness. - Reduce moisture in sand.
Metal Penetration	Metal enters the sand grains, forming rough surfaces.	- Low sand permeability. - High pouring temperature. - Weak mold.	- Increase mold strength. - Reduce pouring temperature. - Use finer sand particles.
Fusion Defect	Metal fuses with sand, creating rough and brittle surfaces.	- High pouring temperature. - Poor sand refractoriness. - High silica content in sand.	- Use high-quality refractory sand. - Reduce pouring temperature. - Modify sand composition.
Flash (Fin)	Thin metal projections at parting lines.	- Excessive mold clearance. - Poor mold clamping. - High pouring pressure.	- Ensure tight mold closure. - Improve mold alignment. - Control metal flow rate.

Common casting defects, their causes, and remedies, helping in improving casting quality and efficiency.

Melting Furnaces

Melting furnaces have been used in metal casting industries to melt and refine metals before pouring them into molds. Different types of furnaces have been used depending on the metal Prepared by **Dr. S. Boopathi**, Professor/ Mechanical Engineering / Muthayammal Engineering College, Namakkal, Tamil Nadu, India.



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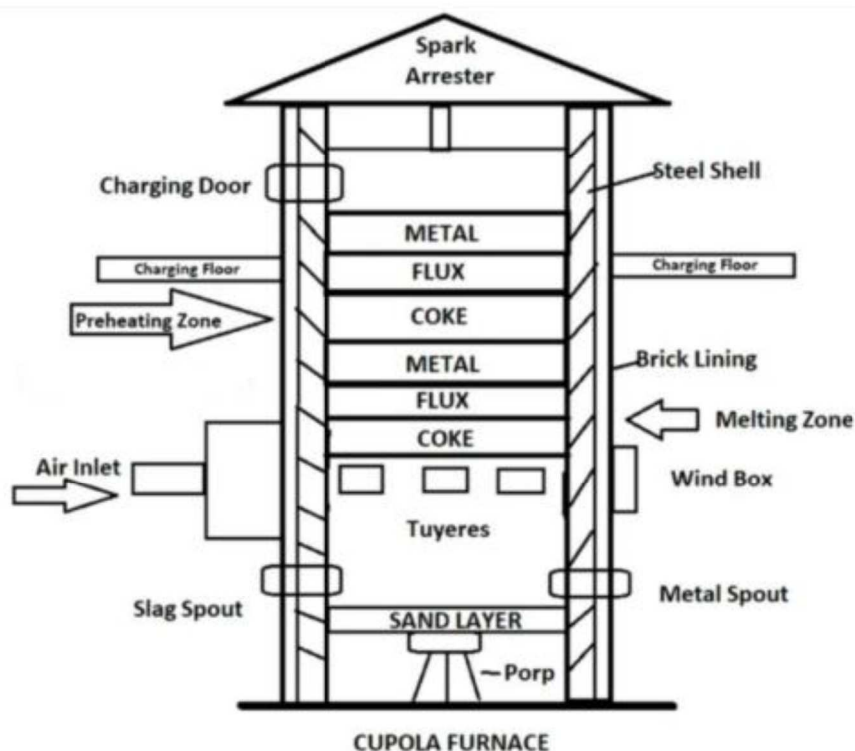
type, production requirements, and energy sources. The choice of a furnace has affected the quality, efficiency, and cost of the casting process.

Types of Melting Furnaces

Type of Furnace	Working Principle	Metals Used	Advantages	Disadvantages
Cupola Furnace	Uses coke as fuel to melt metals by generating high temperatures in a cylindrical, refractory-lined structure.	Cast Iron, Bronze	- Continuous operation - High melting efficiency - Low operating cost	- High pollution due to coke combustion - Not suitable for non-ferrous metals
Induction Furnace	Uses electromagnetic induction to generate heat and melt metals in a refractory-lined crucible.	Steel, Iron, Copper, Aluminum	- High energy efficiency - Precise temperature control - Clean and environment-friendly	- High initial cost - Limited to small and medium batch production
Electric Arc Furnace (EAF)	Uses carbon or graphite electrodes to create an electric arc that melts metal scrap or direct-reduced iron (DRI).	Steel, Alloy Steel, Cast Iron	- Suitable for high-production steel plants - Allows scrap recycling - Precise control of alloy composition	- High energy consumption - Expensive electrodes - Requires high-maintenance
Crucible Furnace	A metal crucible is placed inside a fuel-fired, resistance-heated, or induction-heated chamber for melting small metal batches.	Aluminum, Copper, Zinc, Gold, Silver	- Simple and cost-effective - Suitable for small-scale production and alloy making	- Low production rate - Requires manual handling
Rotary Furnace	A rotating drum furnace that melts metals by tumbling them inside the chamber with heat from fuel combustion.	Lead, Zinc, Aluminum	- Efficient for recycling scrap metals - Suitable for batch production	- High fuel consumption - Requires skilled operation
Reverberatory Furnace	Uses flame heating above the metal surface in a refractory-lined chamber to melt metals.	Aluminum, Copper, Lead	- Good for refining and alloying - Used in large-scale production	- Low thermal efficiency - Long melting time

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Cupola Furnace



The **cupola furnace** has been a **vertically cylindrical, refractory-lined furnace** used primarily for **melting cast iron, bronze, and other ferrous alloys**. It has been one of the oldest and most widely used **continuous melting furnaces** in foundries due to its **high melting efficiency and low operational cost**.

Construction of Cupola Furnace

A typical cupola furnace consists of the following components:

Component	Description
Shell	Cylindrical steel body lined with refractory material to withstand high temperatures.
Charging Door	Opening at the top for loading metal, coke, and flux.
Tuyeres	Air inlets positioned around the furnace to supply hot air for combustion.



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Component	Description
Tap Hole	Outlet near the bottom for molten metal removal.
Slag Hole	A hole located above the tap hole for removing slag impurities.
Bed of Coke	Coke layer at the bottom that acts as a fuel source.
Chimney (Stack)	Exhaust outlet for gases and smoke.

Working Principle of Cupola Furnace

1. **Charging the Furnace:** Layers of **coke, metal (pig iron, scrap), and flux (limestone)** are added through the charging door.
2. **Combustion:** Preheated **air is blown through tuyeres**, igniting the coke and creating temperatures of **1200-1400°C**.
3. **Melting Process:** Heat melts the metal while limestone **removes impurities by forming slag**.
4. **Separation of Slag and Metal:** Lighter slag floats on top and is **removed through the slag hole**.
5. **Tapping of Molten Metal:** The molten metal is **collected at the bottom** and periodically removed through the **tap hole**.
6. **Continuous Operation:** The process continues as long as raw materials are **continuously charged**.

Advantages of Cupola Furnace

- **Continuous Operation:** Enables large-scale metal melting.
- **High Melting Rate:** Suitable for mass production.
- **Cost-Effective:** Uses inexpensive fuel (coke) and materials.
- **Easy Slag Removal:** Ensures impurity-free metal.
- **Recycling Capabilities:** Can melt a mix of scrap iron and pig iron.

Disadvantages of Cupola Furnace

- **High Pollution:** Emits CO₂, SO₂, and particulate matter.
- **Limited Metal Types:** Mainly used for **cast iron and bronze**, not suitable for steel or non-ferrous metals.
- **Energy Inefficiency:** Higher fuel consumption compared to modern electric furnaces.

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- **Manual Operation:** Requires frequent monitoring and skilled labor.

Applications of Cupola Furnace

- **Foundries for Cast Iron Production:** Engine blocks, pipes, machine parts.
- **Steel and Automotive Industries:** Recycling of iron scrap.
- **Bronze and Copper Alloy Casting:** Small-scale alloy production.

Crucible Furnace

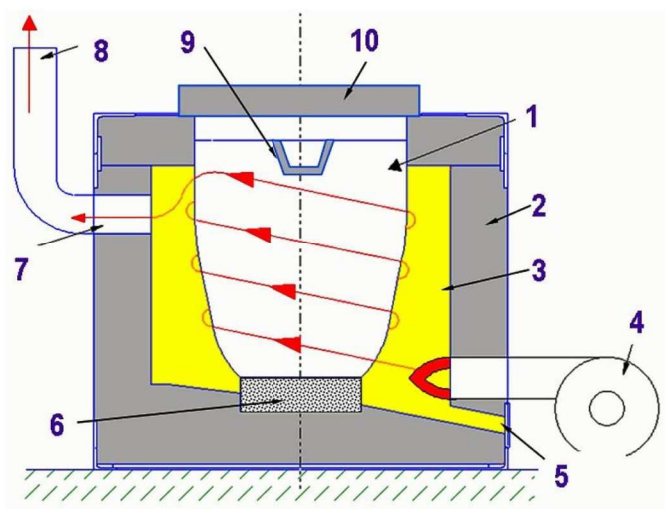


Fig. 1: Schematic diagram of a fuel-fired and tiltable crucible furnace 1) Crucible 2) Furnace lining (permanent lining) 3) Firing compartment 4) Gas or oil burner 5) Emergency tap (leading towards the emergency accumulation pit) 6) Refractory base 7) Lateral exhaust channel (flue) 8) Stack 9) Pouring lip 10) Swiveling lid

A **crucible furnace** has been a **small, high-temperature melting furnace** used for melting **non-ferrous metals** like **aluminum, copper, bronze, and precious metals (gold, silver)**. It has been widely used in **foundries, jewelry making, and small-scale metal casting industries** due to its **simplicity, cost-effectiveness, and ability to handle small batches**.

Construction of Crucible Furnace

A typical crucible furnace consists of the following components:

Component	Description
Crucible	A refractory container (made of graphite, clay, or silicon carbide) that holds the metal during melting.

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Component	Description
Furnace Shell	An outer steel or brick structure lined with refractory material to contain heat.
Burner or Heating Elements	Provides heat through gas, electricity, or coal combustion .
Chimney or Vent	Removes gases and smoke from the furnace.
Lid or Cover	Used to retain heat and prevent oxidation during melting.
Tongs and Lifting Mechanism	Used to handle and pour molten metal safely .

Working Principle of Crucible Furnace

1. **Loading the Metal:** Metal scraps or ingots have been placed inside the crucible.
2. **Heating the Furnace:** The furnace has been fired using **gas, electricity, or solid fuel**, and heat has been transferred to the crucible.
3. **Melting Process:** The crucible has absorbed heat and **gradually melted the metal** without direct contact with flames.
4. **Temperature Control:** The furnace has been adjusted to **maintain the required melting temperature**.
5. **Pouring the Metal:** The molten metal has been removed using **tongs or mechanical lifters** and poured into molds.
6. **Cooling and Cleaning:** The crucible has been cooled down, and slag or impurities have been removed.

Advantages of Crucible Furnace

- **Simple and Cost-Effective:** Low initial investment and operating cost.
- **Versatile:** Suitable for **various non-ferrous metals** and small-batch production.
- **Precise Temperature Control:** Ideal for **alloying and refining processes**.
- **Portable and Flexible:** Can be used in **different locations**.
- **Minimal Metal Contamination:** No direct contact with combustion gases.

Disadvantages of Crucible Furnace

- **Low Production Rate:** Not suitable for large-scale production.

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- **Limited Capacity:** Can only melt small quantities of metal at a time.
- **Manual Operation:** Requires skilled labor for **handling molten metal safely**.
- **Short Crucible Life:** Frequent replacement due to wear and tear from high temperatures.

Applications of Crucible Furnace

- **Jewelry Industry:** Melting gold and silver for ornaments.
- **Small Foundries:** Producing **aluminum, brass, and bronze castings**.
- **Laboratory Research:** Testing new metal alloys.
- **Prototype Development:** Making small batches of custom metal parts.